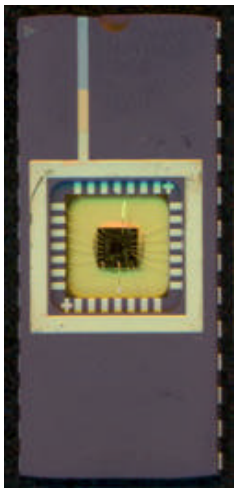
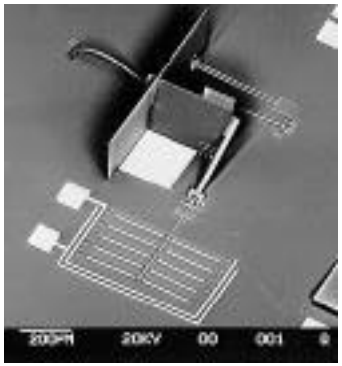
Microelectromechanical Systems

ETO MEMS





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http://eto.sysplan.com/ETO/MEMS/

MEMS Description/Fabrication

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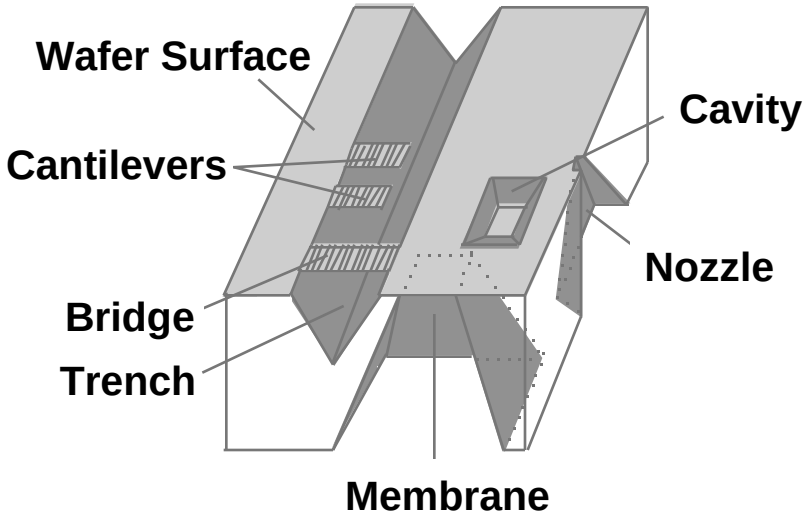
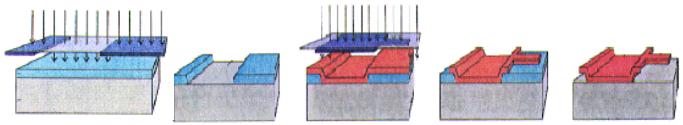
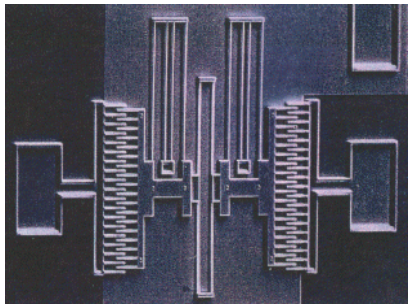
Common MEMS Fabrication Processes



Bulk Micromachining



Surface Micromachining

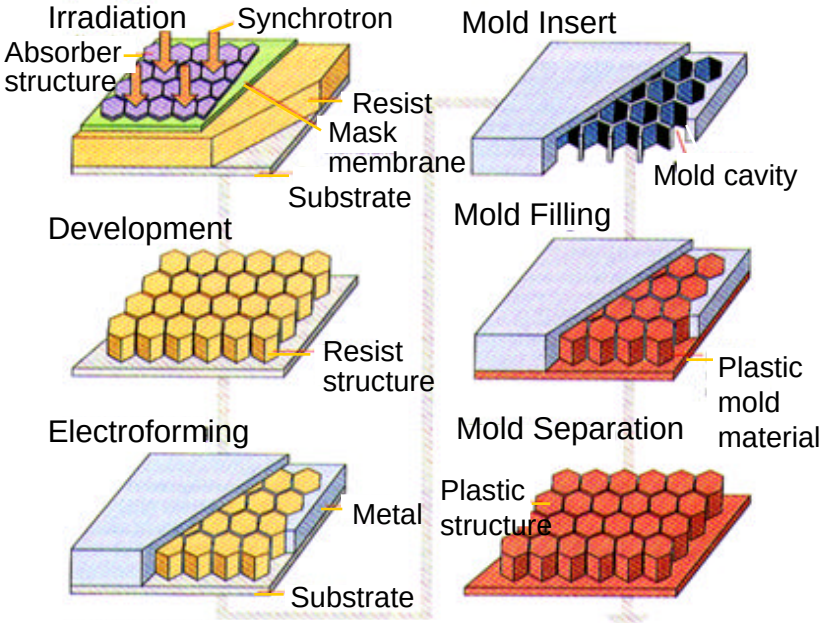


MEMS co-locate sensing, computing, and actuating to change the way we perceive and control the physical world

MEMS Description/Fabrication

ETO MEMS

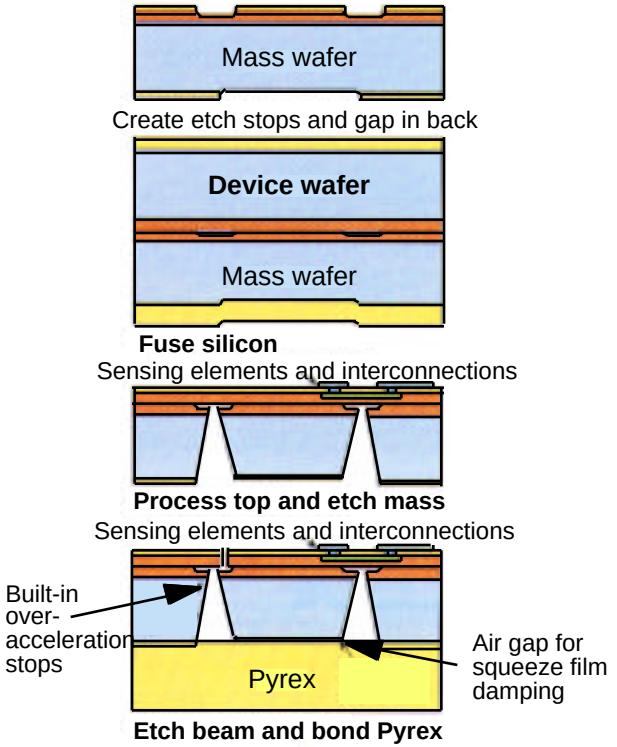
LIGA*, Deep UV



Source: IMM (Mainz Institute for Microtechnology)

*Lithographie, Galvanoformung, Abformung

Wafer-to-Wafer Bonding



MEMS are a new way to make both mechanical and electrical components for microscale flux control

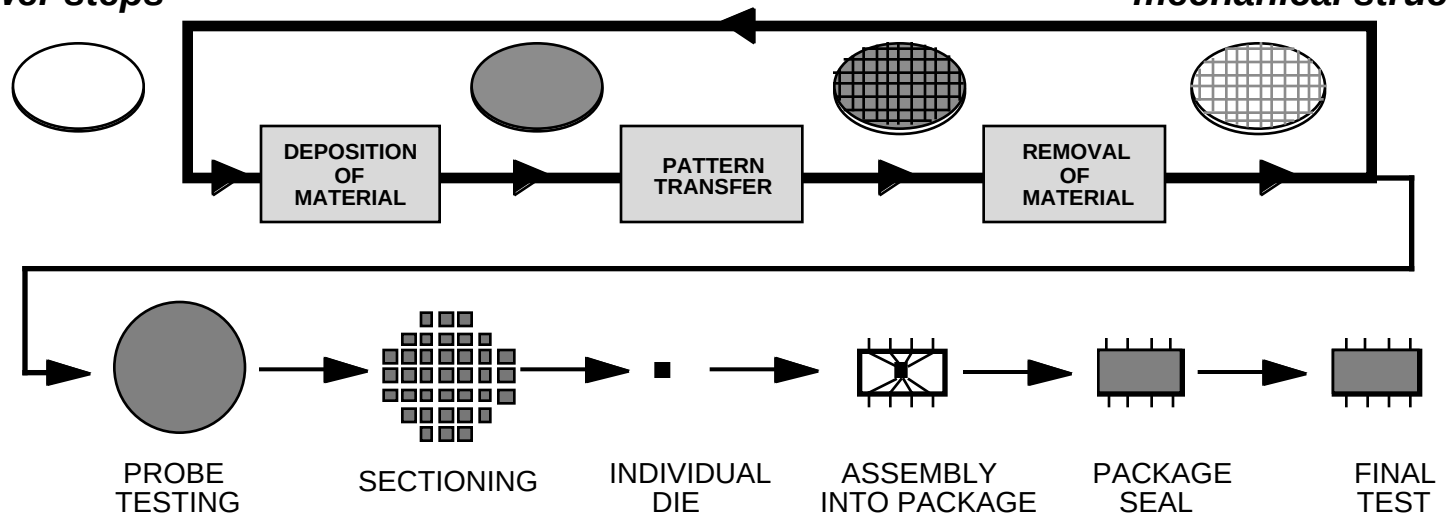
MEMS Builds on Microelectronics Manufacturing

ETO MEMS

Thicker films deeper etches fewer steps

Multiple Processing Cycles

Removal of underlying materials to release mechanical structures



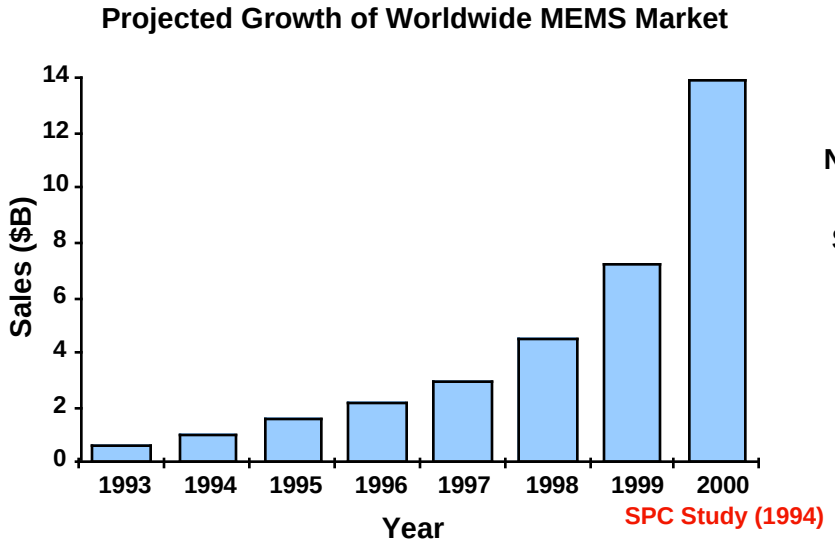
Special probing, sectioning and handling procedures to protect released parts

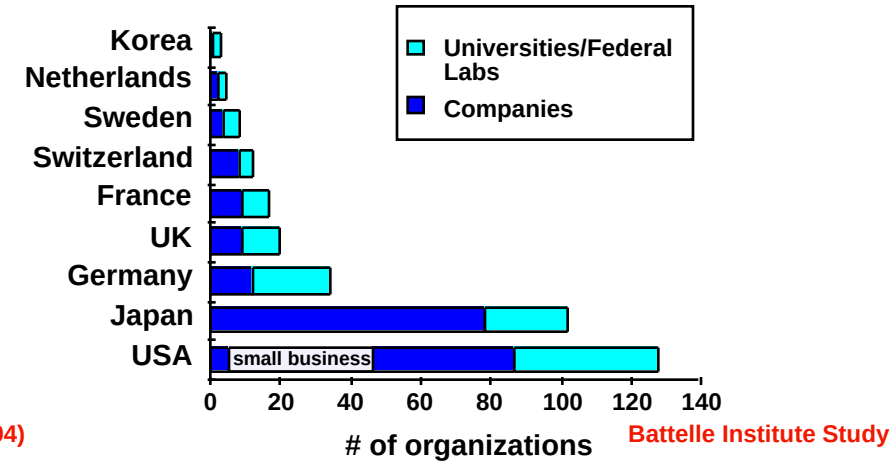
Encapsulate some parts of device but expose others

Test more than just electrical functions

MEMS Market and Industry Structure

ETO MEMS



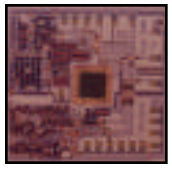


- **Not dominated by defense manufacturers**
- **Populated by diverse industries**
  - sensors
  - industrial & residential controls
  - electronic components
  - computer peripherals
  - automotive & aerospace electronics
  - analytical instruments
  - office equipment

Defense Applications of MEMS

DARPA
ETO MEMS

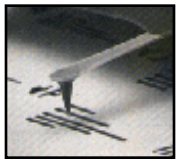
- **Inertial navigation units on a chip** for munitions guidance and personal navigation



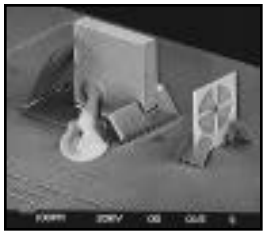
- **Electromechanical signal processing** for ultra-small, ultra low-power wireless communication

- **Distributed unattended sensors** for asset tracking, environmental monitoring, security surveillance
- **Integrated fluidic systems** for miniature analytical instruments, propellant and combustion control

- **Weapons safing, arming and fuzing**
- **Embedded sensors and actuators** for condition-based maintenance



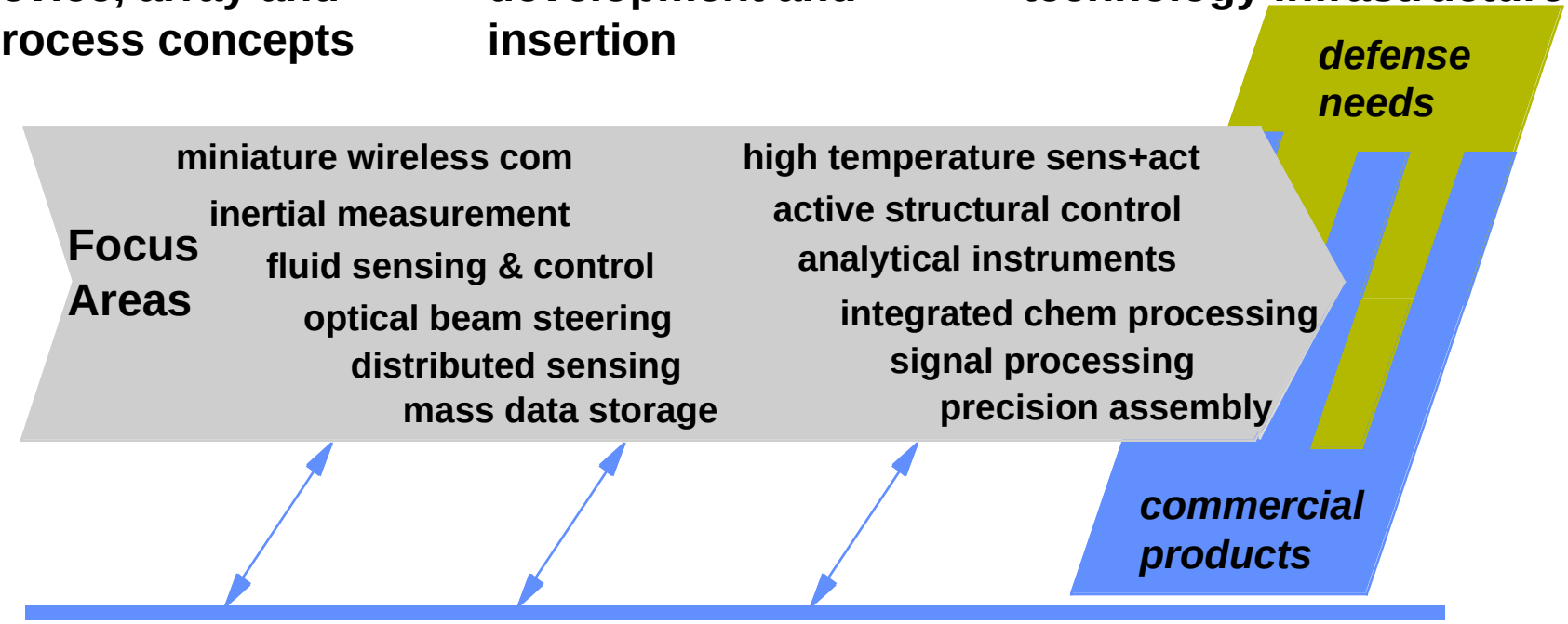
- **Mass data storage devices** for high density, low power
- **Integrated micro-optomechanical components** for identify-friend-or-foe systems, displays and fiber-optic switches
- **Active, conformable surfaces** for distributed aerodynamic control of aircraft and adaptive optics



MEMS Program Objectives and Plan

ETO MEMS

- Realize advanced device, array and process concepts
- Accelerate systems development and insertion
- Catalyze a distributed technology infrastructure



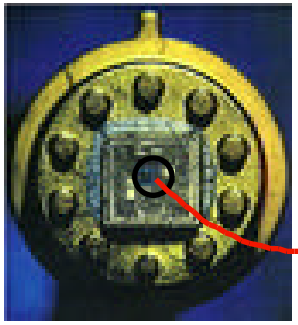
Support & Access Technologies

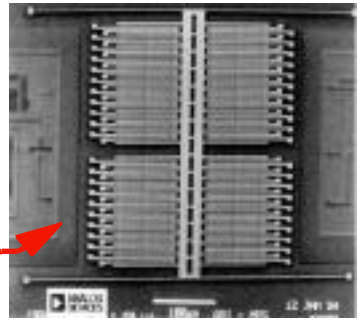
Shared design, fabrication and assembly services
Distributed data and knowledge networks
Manufacturing and packaging equipment
Test, visualization and characterization tools

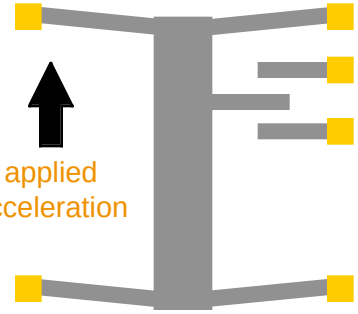
Inertial Instruments on a Chip

ETO MEMS

ADXL-50







- +/- 50g full scale
- DC to 1 khz
- 200g shock
- 5 volt power supply
- $10 each in volume
- 200 transistors
- Integrated self-test, signal conditioning
- Manufactured on modified IC line

Funding Strategy

Defense Needs

self-testing fuzes

safing & arming

intrusion, tamper and motion detection

condition-based maintenance

inertial guidance for munitions

platform stabilization

personal and vehicle navigation

commercial investments

defense investments

higher performance levels

3-4 orders of magnitude lower drift rates & higher resolution, multiple degrees of freedom

air-bag sensors

side-impact sensors

suspension control

shock sensors

anti-lock braking systems

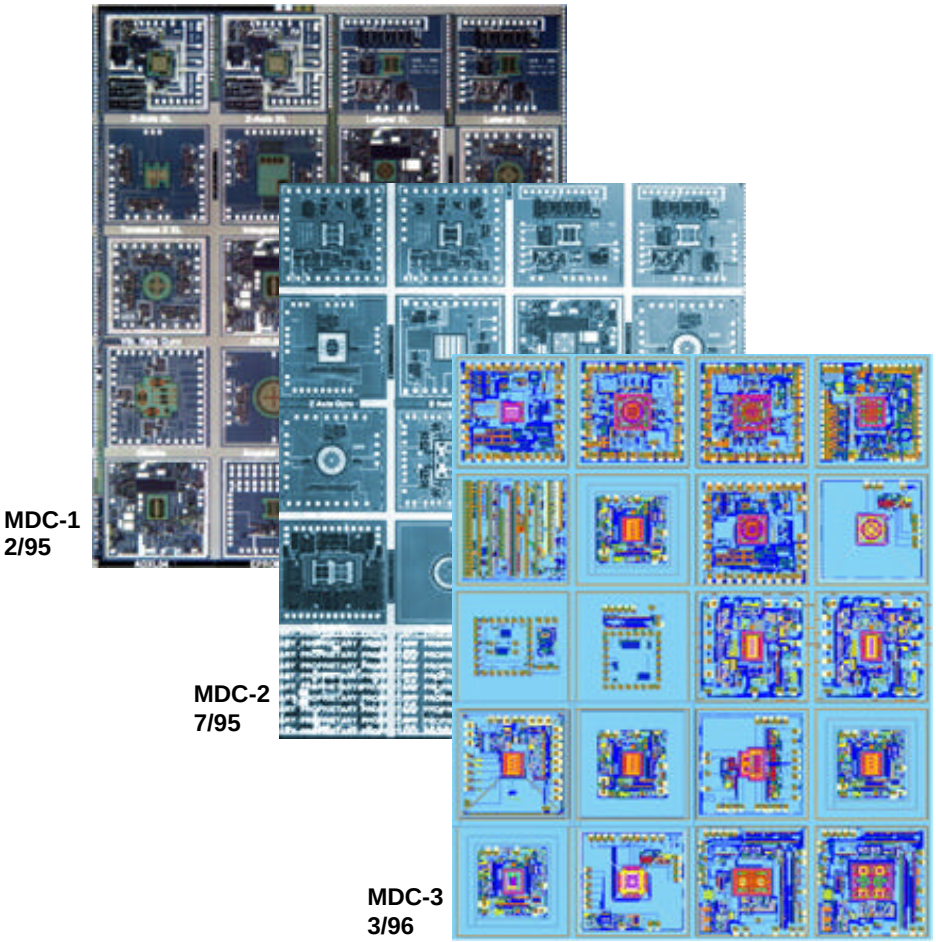
camcorder stabilization

automobile navigation

Commercial Drivers

Multiple Device Chips

ETO MEMS



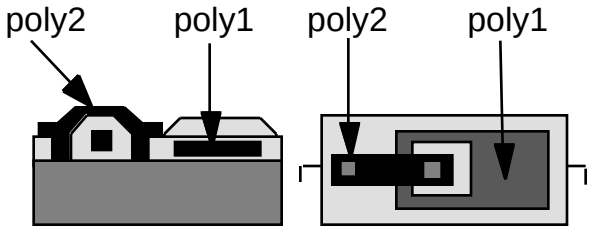
- z-axis accelerometers
- lateral accelerometers
- angular accelerometers
- integrator structures
- vibrational rate gyros
- high-Q EM filters
- lateral oscillators
- flow sensors
- resonant accelerometers
- EPROMs
- ADXL05
- ADXL50
- ADXL75
- signal processing elements

Analog Devices/UC Berkeley

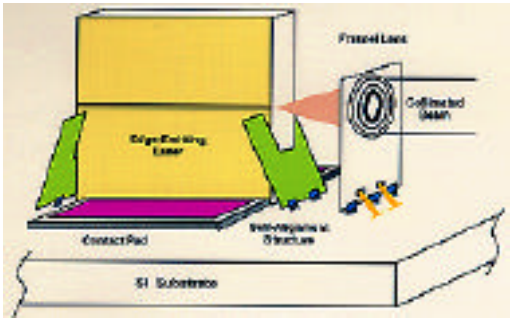
Optical MEMS Components

ETO MEMS

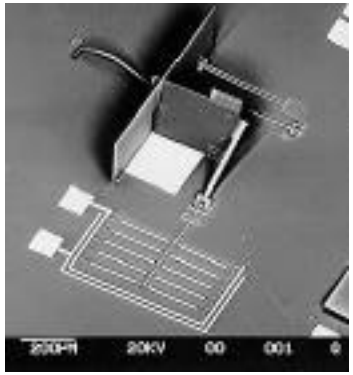
Fabrication sequence

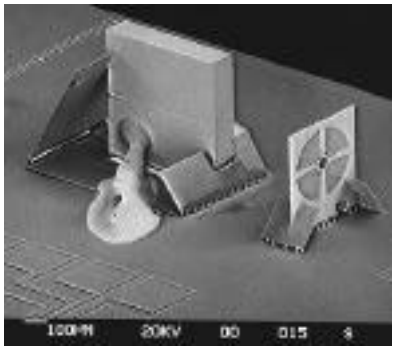


Integrated optical components



Corner cubes





- Out-of-plane hinged structures fabricated in-plane
- Integrated micro-optomechanical components that are subsequently “assembled”

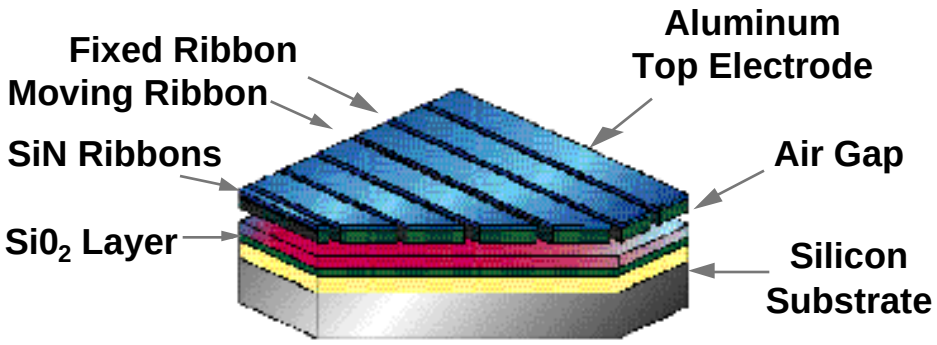
- Corner cube reflectors (low-power, line-of-sight communications and identify-friend-or-foe)
- Optical interconnects and aligners

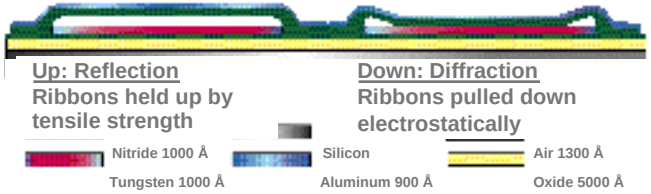
UCLA

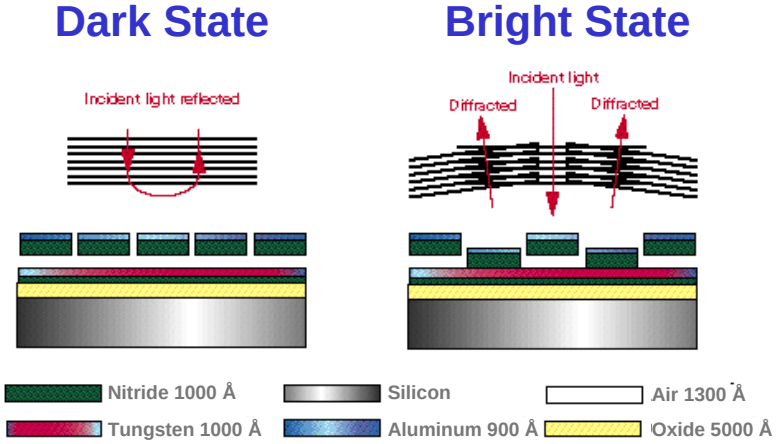
Optomechanical Displays

ETO MEMS

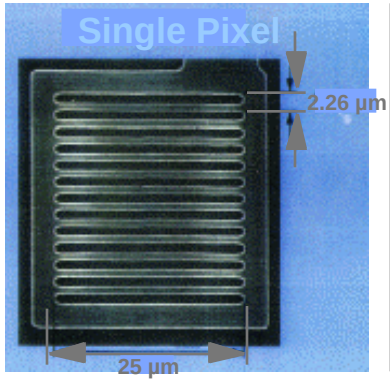
Grating Light Valves

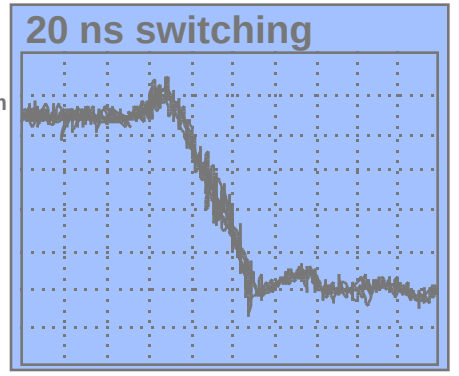






- Silicon surface-micromachined, deformable grating modulator
- No phosphors or liquid crystals
- Low-power, bi-stable switching
- RGB color capability
- 20 nanosecond switching time
- Full motion video
- Digital gray scale



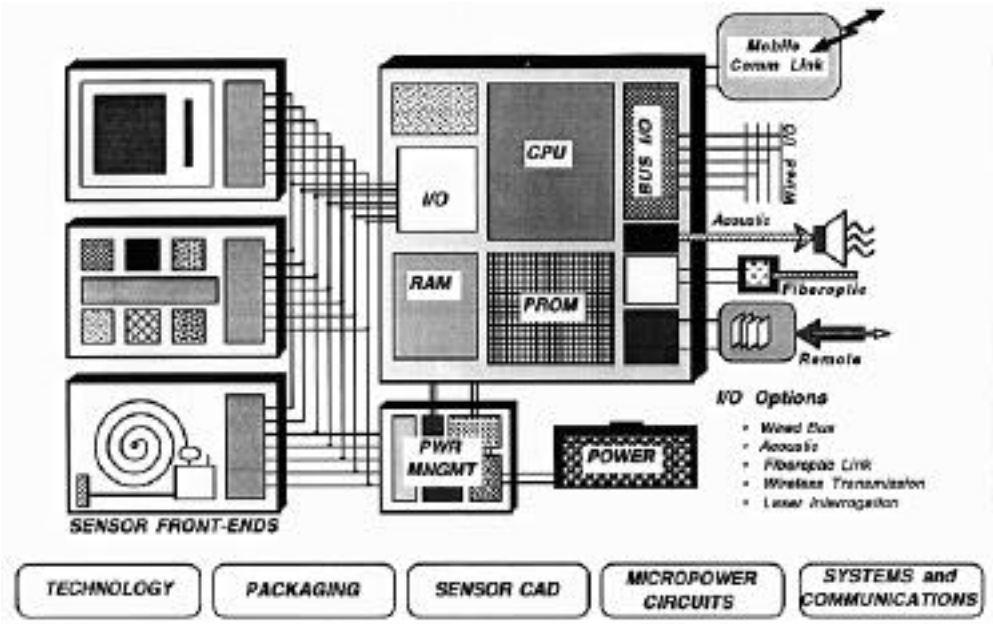


Silicon Light Machines

Environmental Monitoring Sensor Cluster

ETO MEMS

Wristwatch-sized generic sensor cluster - measurement of temperature, barometric pressure, & vibration



Telemetry Range:	50 ft.
Average Power Dissipation:	<500 µW
Portable Operating Life:	120 days
Barometric Pressure Range (Abs):	550–850 Torr
Ambient Temperature Range:	–20 to +60° C
Humidity Measurement Range:	30–90% RH
Acceleration Range:	+/– 2g

Specific Applications:

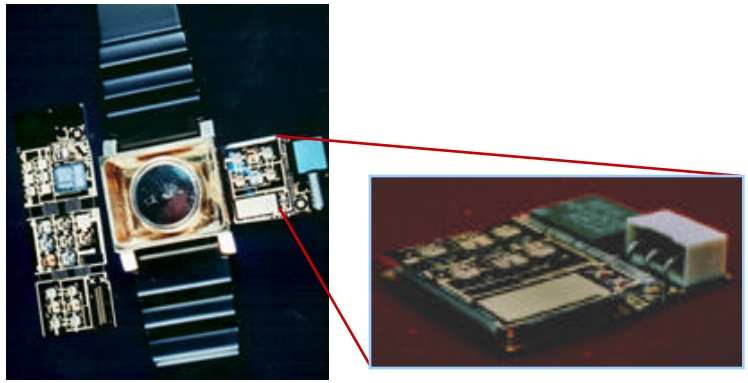
Air Force Phillips Laboratory
Airport Weather Monitoring

Naval Research Laboratory
Unmanned Air Vehicle Applications

Naval Research Laboratory
Ocean Buoy-Mounted Environmental Sensing

Marine Science Advisor
Environment/Weather Sensors

Department of Transportation
Airport Weather Monitoring

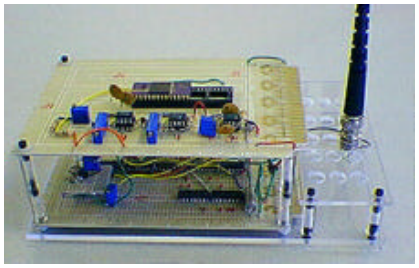


University of Michigan

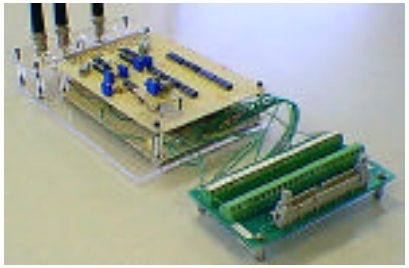
Low Power Wireless Integrated Microsensors (LWIM)

ETO MEMS

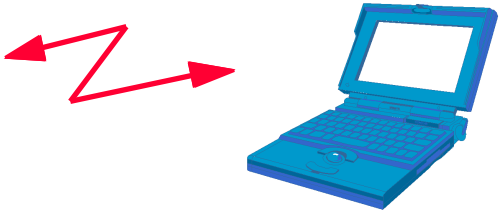
- **Distributed, autonomous, wireless microsensor network with signal processing decision capability**
- **Single-chip RF transceiver integrated with sensors and integrated RF components**
- **Low power/low noise analog signal processing based on weak inversion CMOS**



LWIM-I node



LWIM-I low power receiver and base station interface



PC-notebook base station and LWIM Windows interface

Emerging Applications

battlefield awareness
situational awareness
munitions targeting
condition-based maintenance
environmental monitoring
biomedical monitoring
civil safety and security
commercial manufacturing
transportation

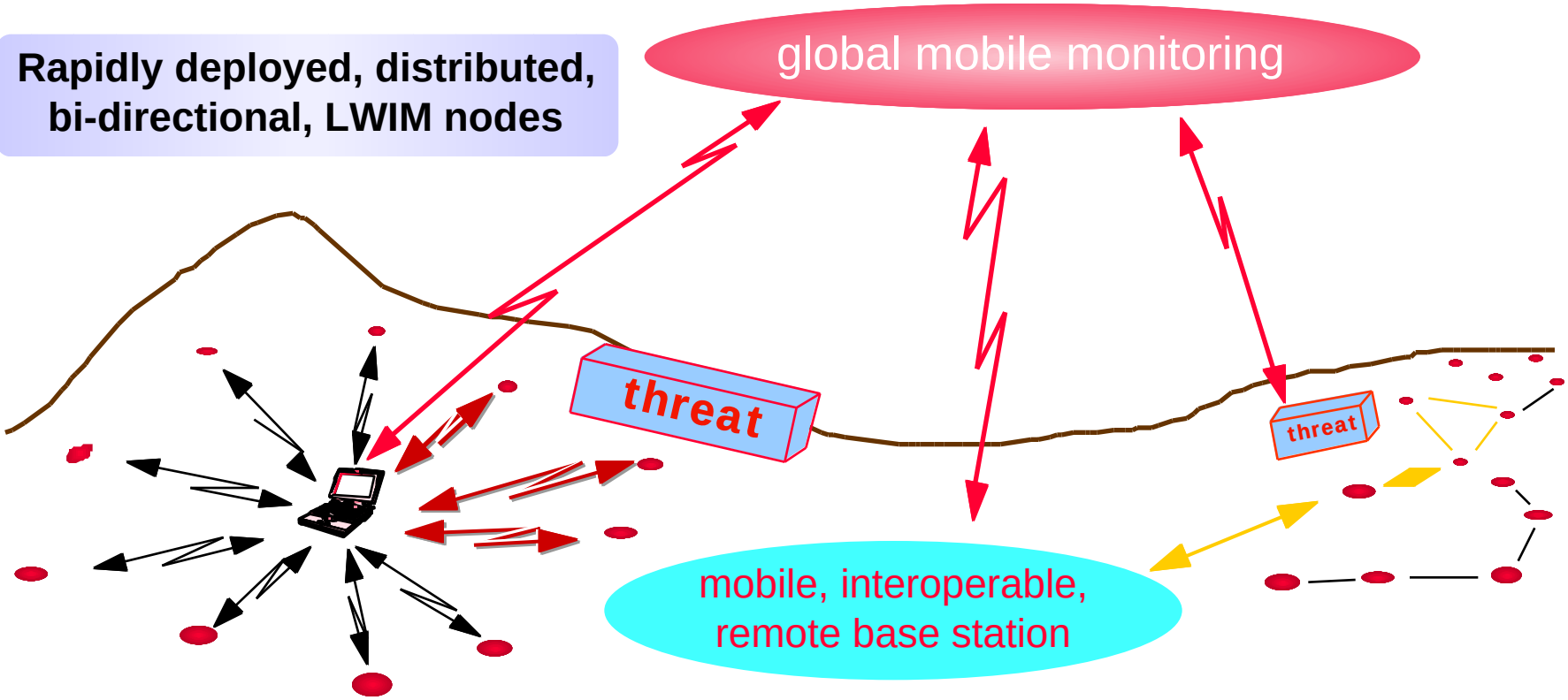
surveillance, perimeter and base security
detection, identification, tracking
munitions impact, target location
vehicle, powerplant, transmission, propulsion
external and internal local and global control
personnel health status monitor
residence, commercial, public structures, urban
precision machining with low cost tools
IVHS, vehicle control

UCLA/Rockwell

LWIM Intelligent Distributed Nodes: Tactical Remote Sensor Systems

DARPA
ETO MEMS

Rapidly deployed, distributed, bi-directional, LWIM nodes



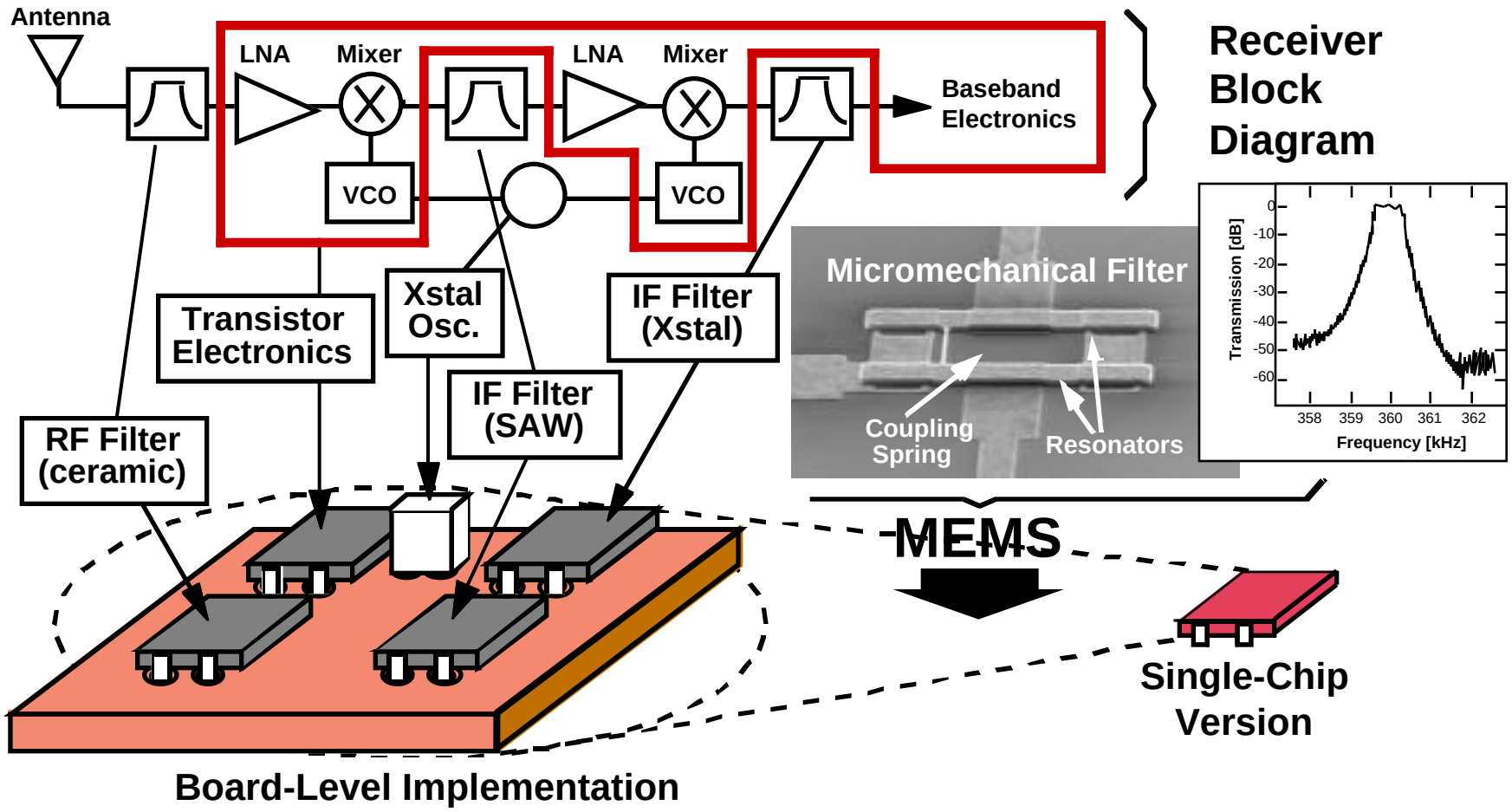
surveillance *perimeter*

reconnaissance *network*

UCLA/Rockwell

Radio-Frequency MEMS

ETO MEMS

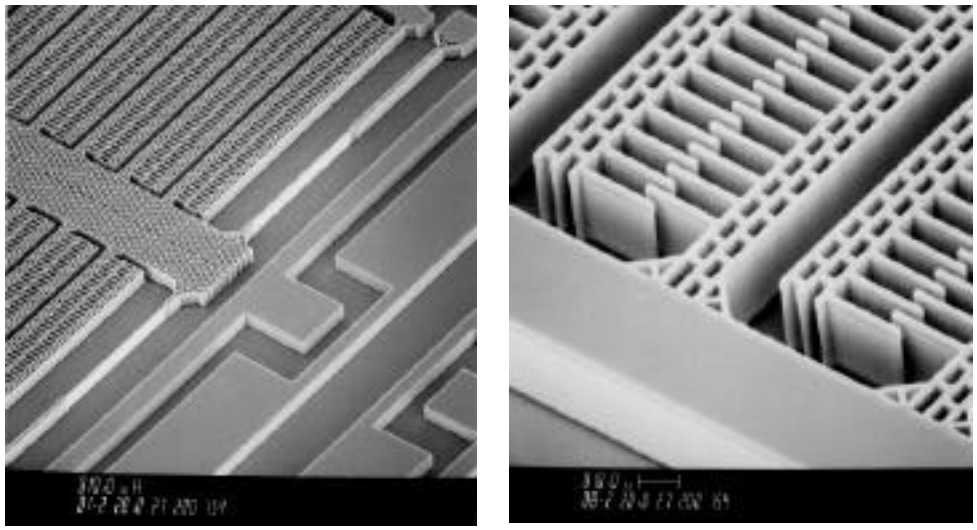


Radio Frequency MEMS

ETO MEMS

- **Technical challenges**
  - Antenna, Frequency Band, Size, Weight, Power
- **MEMS solution**
  - Replace discrete, off-chip components (switch, varactor, inductor)
  - Replace entire electrical circuits with electromechanical signal processing (filters, oscillators, modulators, de-modulators)

- **Single Crystal Silicon**
- **Superior Mechanical Properties**
- **High Aspect Ratio (20 to 1)**
- **Higher Linearity**
- **Large Tuning Ratio (> 6.5 to 1)**



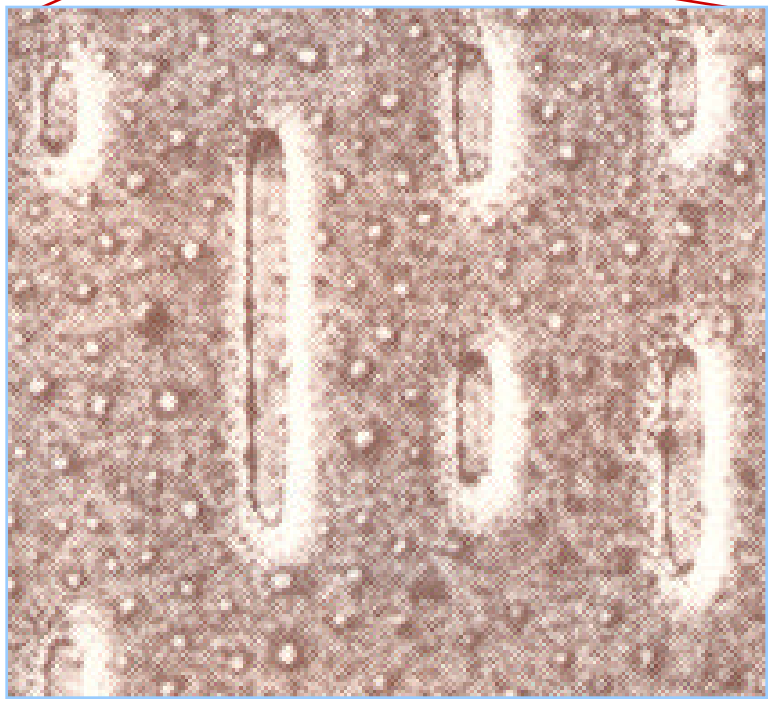
SEM micrographs of the MEMS tunable capacitor

Rockwell

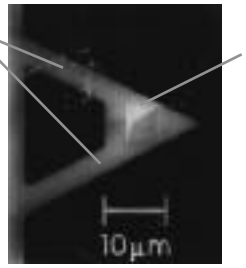
Mass Data Storage

ETO MEMS

Compact Disk
~620 MBytes in ~23 in^2



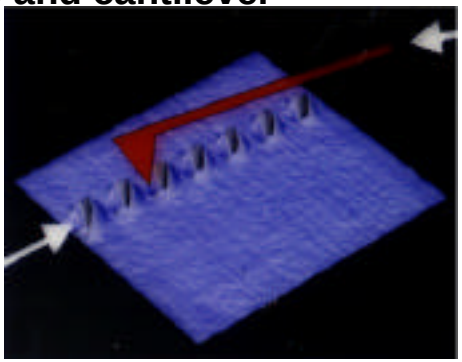
Cantilever



Writing tip

Atomic Resolution Data Storage

Micromachined silicon read/write tip and cantilever



Micromachined stylus

Data track

Data pits read using AFM techniques

Written data pits

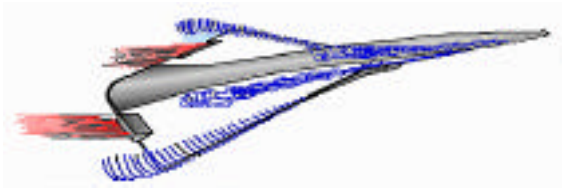
~50 GBytes in same area (8x)

IBM

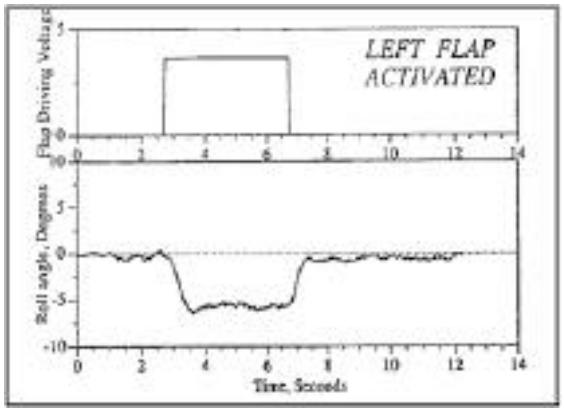
Active Conformable Surfaces

ETO MEMS

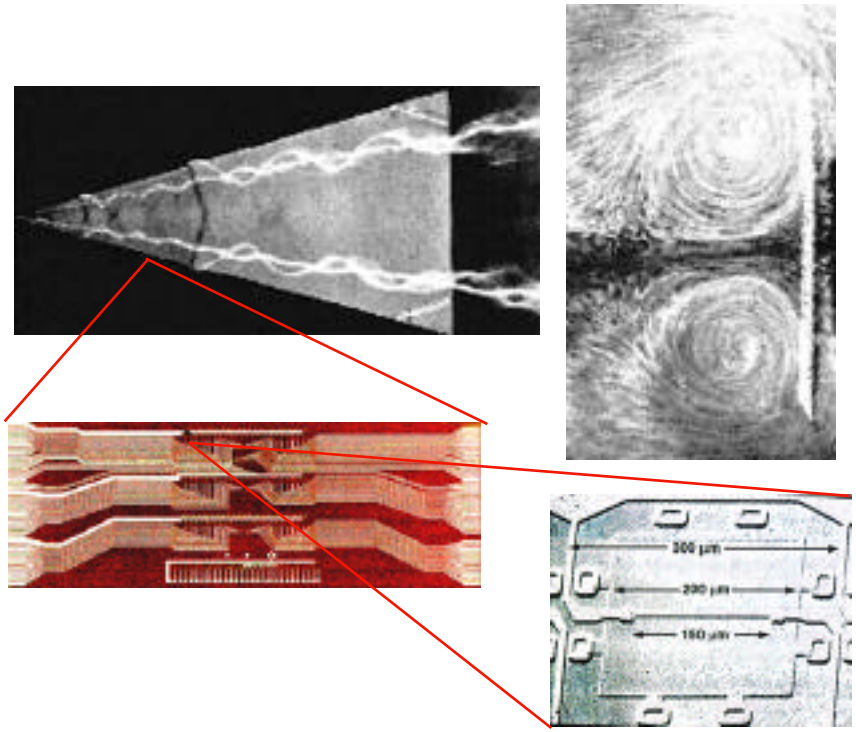
Advanced Aerodynamic Control



Distributed MEMS sensors & actuators control separation of leading-edge vortices



Wind tunnel roll measurements

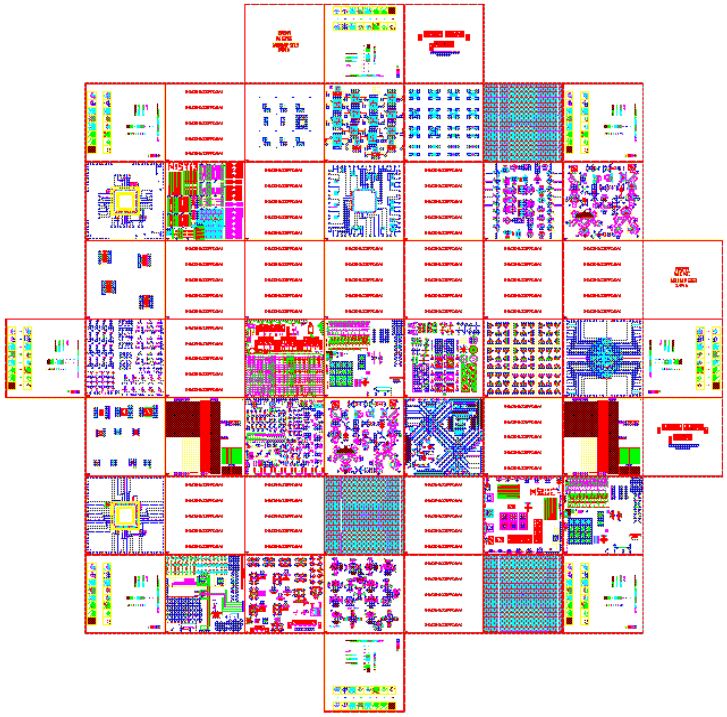


- **Aircraft and projectiles with no large, discrete control systems**
- **Higher maneuverability, greater lift, reduced drag**

UCLA/CalTech

MCNC-DARPA
Multiproject Chip Run

ETO MEMS



MUMPs13

MCNC-DARPA MEMS Multiproject Run

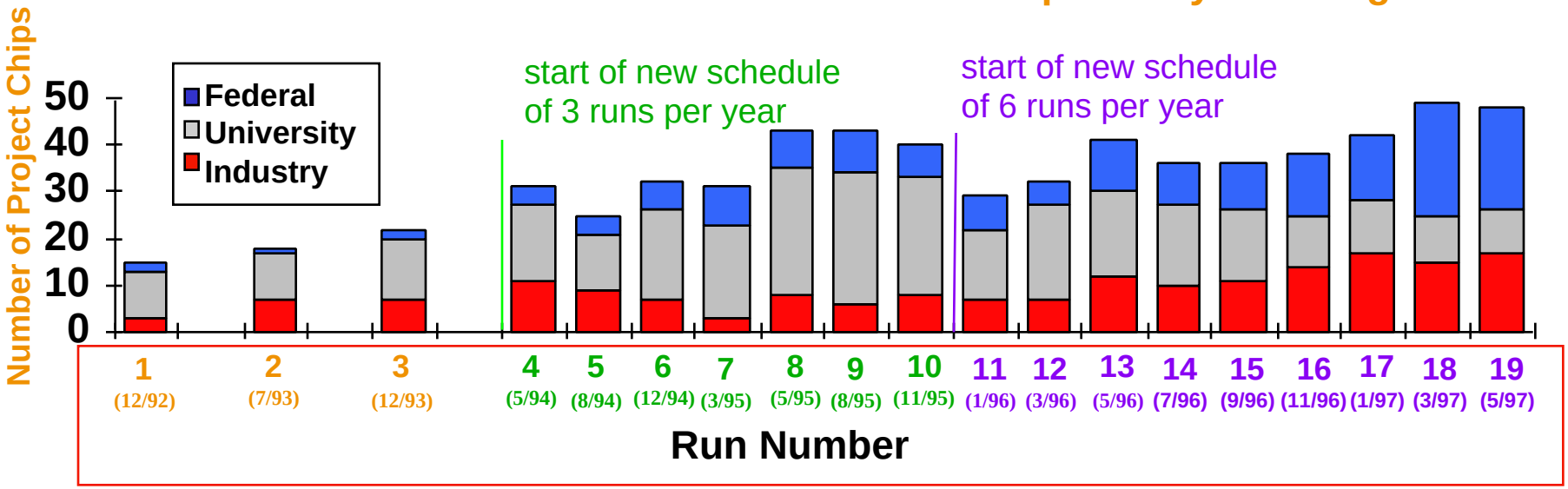
MCNC

Multi-User MEMS Projects (MUMPs)

ETO MEMS

Accelerating innovation and commercialization by providing MEMS fabrication technologies to multiple, remote users

$850 + design → **MCNC (10 weeks later)** → **one dozen 1 cm x 1 cm MEMS chips with your design**



30% of users are getting their first access to MEMS technology through MUMPs

~ 550 projects, 1000 users in total

MCNC